

ARMY RESEARCH LABORATORY



Dynamic Analyses of the Mortar Dragster Tab Mechanism

John A. Condon
Michael S.L. Hollis

ARL-TN-107

APRIL 1998

DTIC QUALITY INSPECTED 4

19980527 080

Approved for public release; distribution is unlimited.

AutoCAD® R14 is a registered trademark of Autodesk, Inc.

Windows™ is a trademark of Microsoft Corporation.

Working Model® 3D is a registered trademark of Working Model, Inc., a division of Knowledge Revolution.

The findings in this report are not to be construed as an official Department of the Army position
unless so designated by other authorized documents.

Citation of manufacturer's or trade names does not constitute an official endorsement or approval of
the use thereof.

Destroy this report when it is no longer needed. Do not return it to the originator.

Army Research Laboratory

Aberdeen Proving Ground, MD 21005-5066

ARL-TN-107

April 1998

Dynamic Analyses of the Motar Dragster Tab Mechanism

John A. Condon

Michael S.L. Hollis

Weapons and Materials Research Directorate

Approved for public release; distribution is unlimited.

Abstract

As a means of verifying the design and operation of the Mortar Dragster, a commercially available, three-dimensional rigid body dynamics simulation program was exercised. The Mortar Dragster is a conceptual design for a range correction device for the 81-mm mortar. The design includes a series of drag surfaces, or tabs, which are actuated at some point in the trajectory of the projectile. The actuation places the entire series of drag surfaces into the airstream, thus slowing the projectile. Of specific interest are the collision forces and resulting tab hinge loads imparted by the opening tabs impacting the adjacent connected body because of integral torsion springs and air drag-induced torque loads. Collision forces predicted by the simulation program were of the same order of magnitude as hand calculations. The results of this investigation provided confidence in the final design of the tab mechanism before its flight testing and also provided further verification of the simulation program's performance.

TABLE OF CONTENTS

	<u>Page</u>
LIST OF FIGURES	v
1. INTRODUCTION	1
2. HAND CALCULATIONS	1
3. KINEMATIC ANALYSIS	4
4. CONCLUSION	7
REFERENCES	11
DISTRIBUTION LIST	13
REPORT DOCUMENTATION PAGE	17

INTENTIONALLY LEFT BLANK

LIST OF FIGURES

<u>Figure</u>	<u>Page</u>
1. Mortar Dragster Device	2
2. Force Diagram	3
3. WM3D Model	5
4. Tab Diagram	6
5. Predicted Rotation of Tab at Time Step of 0.0005 Second	8
6. Predicted Rotation of Tab at Time Step of 0.00005 Second	8
7. Predicted Angular Acceleration at Time Step of 0.0005 Second	9
8. Predicted Angular Acceleration at Time Step of 0.00005 Second	9
9. Predicted Contact Force at Time Step of 0.0005 Second	10
10. Predicted Contact Force at Time Step of 0.00005 Second	10

INTENTIONALLY LEFT BLANK

DYNAMIC ANALYSES OF THE MORTAR DRAGSTER TAB MECHANISM

1. INTRODUCTION

This work is in support of the Light Forces mission program at the U.S. Army Research Laboratory (ARL). Mortar Dragster is a concept that will provide a flight control module for existing mortar projectiles in an effort to reduce munition range error. The concept entails a simple inertial measurement unit (IMU) encapsulated in a small drag control device. The device will be small enough so that the infantry soldier's extra carrying burden will be minimal. The soldier can use the device in the field by merely screwing it onto the mortar body where the fuze is normally placed. The fuze then screws onto the other end of the drag module body. The drag device will be given the firing and target coordinates before launch. The soldier will then fire the mortar at a point past the target. Once in flight, the on-board IMU will determine the range error to the target and will deploy the drag device at the proper time. Thus, the mortar decelerates and impacts the target. The purpose of this concept is to provide the Army Light Forces with more effective firepower with only a miniscule increase in logistic burden.

During flight, the actuation and rotation of each tab are initiated by the unloading of the torsion spring. As a tab rotates outward from the drag module body and into the airstream, the projected frontal area of the tab is increased. The combination of the spring load and drag increases the torque about the pivot axis of the tab. Momentum of the tab is at a maximum at the "full open" position just before impact with the [connected] body. This collision force required to decelerate the rotating tab to a stop position is the subject of this report. It is important to accurately know this value while designing the tab mechanism in order to prevent failure during the flight test.

A picture of the mortar dragster device (in both closed, i.e., launch configuration, and open, i.e., deployed configuration) is shown in Figure 1. This report focuses on and briefly discusses the hand calculations and kinematic analysis that have led to the design and validation of the tab mechanism.

2. HAND CALCULATIONS

In an effort to design the dragster device and verify the simulation program, a simple hand calculation was performed. The calculation required the fundamental equations of dynamics specifically for rigid body motion about a fixed axis. This approach is simple and conservative.

These equations were used to determine the angular velocity of the tab before the tab impacts a stop (drag module body) which ends the pivot cycle. At that point, the angular deceleration of the tab is calculated by dividing the angular velocity by the impact duration. The duration of impact is uncertain; however, a time of 0.5 millisecond was chosen because it is of the order of impact duration seen on an in-house shock table. With the impact angular deceleration determined, the torque and resulting forces attributable to impact can be determined.

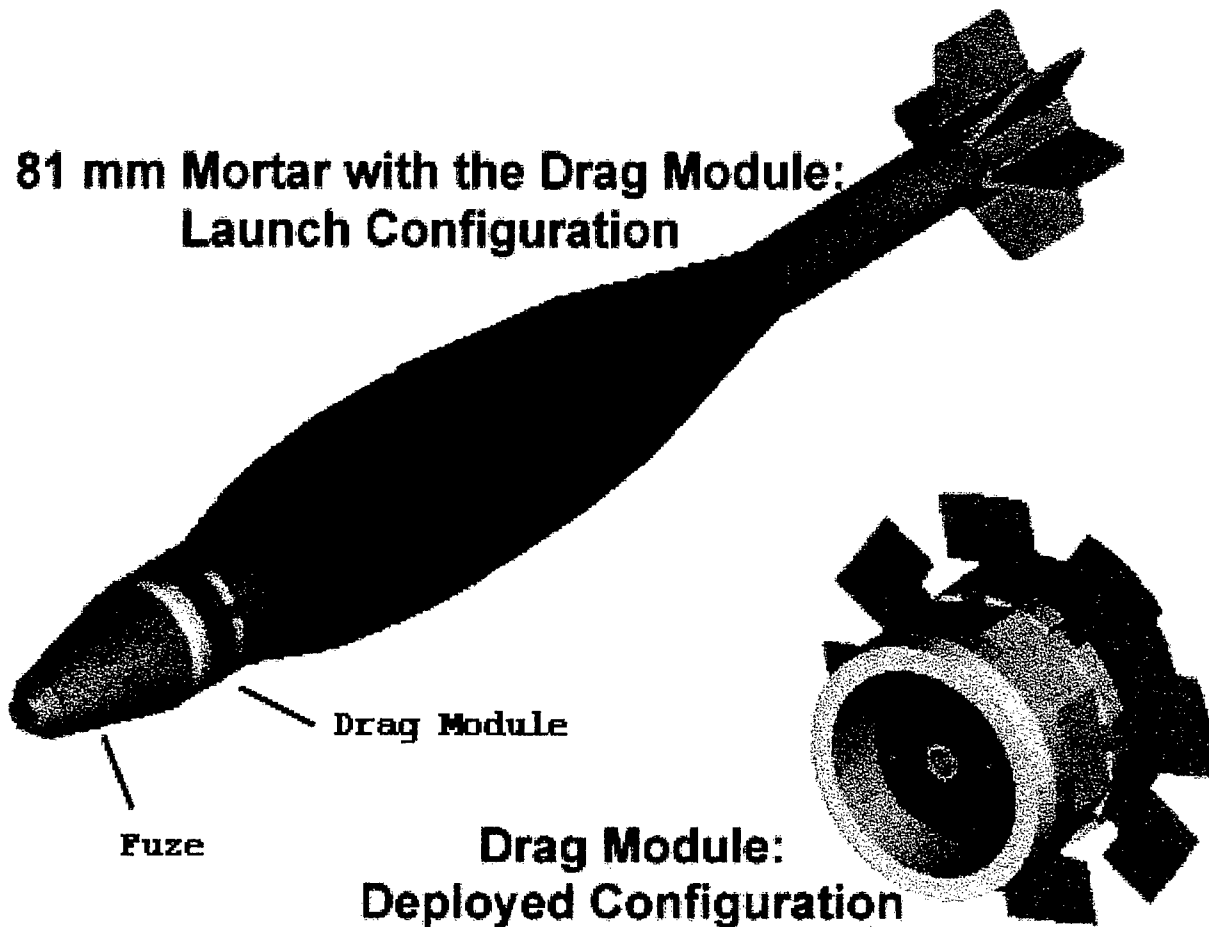


Figure 1. Mortar Dragster Device.

Figure 2 displays a force diagram that indicates the forces and torques attributable to the aerodynamic load and the torsion spring. A summation of the moments about the pivot point yields the equation

$$M_t = T_s + F_a r.$$

in which

M_t = Total moment before the end of the pivot cycle.

T_s = Torque attributable to torsion spring, assumed to remain constant. The spring was rated at 0.0088 N-m (0.078 lb-in). This spring load was

estimated by multiplying the manufacturer's rating of 0.00111 lb-in/deg. by a 70° angle deflection.

F_a = Aerodynamic load attributable to tab being fully deployed into the airstream.

This drag force equates to 15.40 N (3.46 lb). This value was also held constant even though the load is at a maximum when the tab is fully deployed at a free flight velocity of 310 m/s.

r = Arm radius from the center of gravity of the tab to the hinge point. This value measures 0.009 m (0.354 in.).

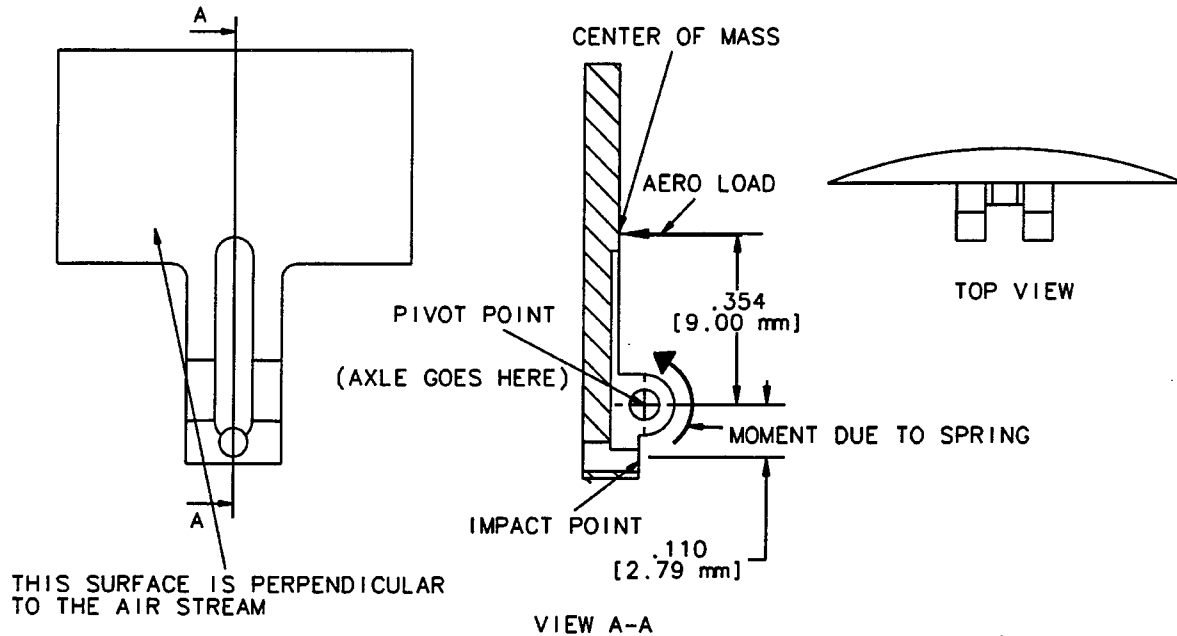


Figure 2. Force Diagram.

The total moment equates to 0.1473 N-m. The moment is equivalent to the total torque $T_t = I_0 \alpha$.

in which

I_0 = The moment of inertia of the tab about the pivot point ($1.26 \times 10^{-6} \text{ kg-m}^2$).

α = The angular acceleration of the tab before the end of the pivot cycle.

Solving for α , the angular acceleration is $1.169 \times 10^5 \text{ rad/s}^2$. Using the α , the angular velocity before the end of the pivot cycle is found using the simple equation

$$\omega^2 = \omega_0^2 + 2\alpha(\Theta - \Theta_0),$$

in which

ω = The angular velocity before the end of the pivot cycle.

ω_0 = The initial angular velocity, which is 0.

$\Theta - \Theta_0$ = The difference of final and initial pivot angles, which are $\pi/2$ and 0.

The resulting angular velocity is 606.0 rad/s. The time rate of change of the angular velocity will determine the angular deceleration. Dividing the angular velocity by 0.0005 second results in an angular deceleration of $1.212 \times 10^6 \text{ rad/s}^2$. This angular deceleration is then used to determine the impact torque on the tab. The equation of interest is

$$T_f = I_o \alpha_f = F r_s$$

in which

T_f = The final or deceleration torque.

$I_o \alpha_f$ = The moment of inertia of the tab about the pivot point ($1.26 \times 10^{-6} \text{ kg-m}^2$) multiplied by the angular deceleration ($1.212 \times 10^6 \text{ rad/s}^2$).

$F r_s$ = The impact force of the stop on the back end of the tab multiplied by the short radius arm of the impact point to the pivot point (0.0028 m).

The resulting force is 545.40 N or 122.56 lb. The resulting force is used to determine the shear stresses in the hinge portion of the tab. These stresses were determined to be well within the limits of the tab and axle material strengths. Based on these results and the conservative approach, the simulation results should reveal impact forces less than calculated.

3. KINEMATIC ANALYSIS

The kinematic analysis of the tab mechanism was performed using the commercially available program entitled Working Model® 3D version 3.0 (WM3D) by Knowledge Revolution. WM3D is a three-dimensional dynamics simulation program for desktop computers running the Windows™ operating system [1].

A solid model (ACIS *.sat format file) of one of the tab mechanisms was created in AutoCAD® (computer-aided design) Release 14 and translated into a WM3D format file [2]. A shaded rendering of the WM3D model is shown in Figure 3. A revolute spring damper was created between the tab and connected body (a portion of the whole part design), allowing the tab to freely rotate through a 90° arc whose pivot axis of rotation is that of the axle. The spring constant value was input as specified by the manufacturer (0.00111 lb-in/deg, spring load linearly decreased as tab opened). The state-of-rest angle (i.e., natural angle) for this spring was input as 95° upon visual inspection. The connected body was anchored to the background. The axle geometry exists only as an aid in visually interpreting the model and positioning the tab and connected body with respect to one another. The tab's physical properties were calculated by the program, which required only material density and accurate geometric modeling from the user. Creation of the stop part shown in Figure 3 was required in order to acquire contact force information with respect to the tab collision; that is, contact force information could not be acquired between the tab and connected body once the

revolute joint was created between these two parts. (In terms of the actual hardware, the stop and connected body are one and the same.) The stop part was anchored to the background.

WM3D MODEL OF TAB MECHANISM IN DEPLOYED CONFIGURATION

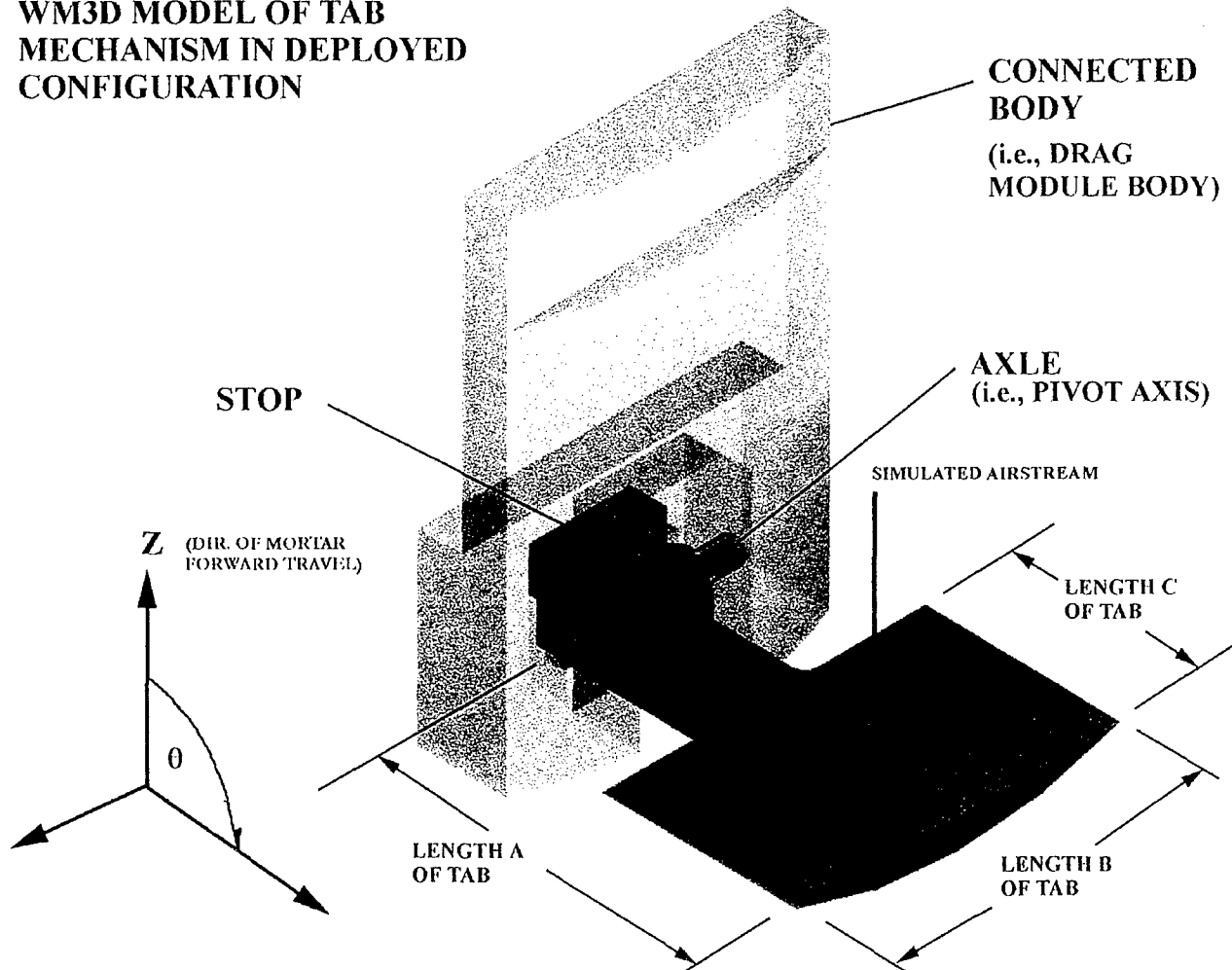


Figure 3. WM3D Model.

A number of initial runs of the model without the air drag loading were performed in order to validate and size the damping coefficient of the revolute spring damper. (Note, this damper value was not provided by the manufacturer.) A static actuation (i.e., module body resting on bench) of the tab mechanisms in the fully assembled fabricated prototype revealed an opening time (time for tab to rotate through 90° and contact stop part) of ≤ 0.033 second as interpreted by 30 frames per second very high speed (VHS) video (i.e., the tabs opened in less than one frame of video). The most successful iteration of the WM3D model allowed for a tab opening time of 0.022 second with a damping coefficient value of $1e^{-5}$ lb.-in.-sec./deg. (solution time step of 0.00005 sec.)

The air-drag loading was input as an additional torque between the connected body and tab. A trigonometric relation was created to allow for an increasing drag load as the frontal area of the tab increased because it was rotated into a "simulated" airstream. The derivation of this relation is shown below (see Figures 3 and 4.)

$$\text{Drag} = .5\rho V^2 C_d S$$

$$\text{Tab Drag Torque} = \text{Drag} (\theta) \bullet \text{Lever Arm} (\theta)$$

$$\text{Drag} (\theta) = [.5\rho V^2 C_d S] \bullet \sin (\theta) \bullet (1/386.22 \text{ in/s}^2)$$

$$\text{Lever Arm} (\theta) = [\sin (\theta) \bullet (\text{length A of tab})] - [.5 \bullet \sin (\theta) \bullet (\text{length C of tab})]$$

$$\text{Tab Drag Torque} = 1.670 \sin^2 \theta \text{ (in - lb)} \quad [.189 \sin^2 \theta \text{ N-m}]$$

in which

$\rho = 4.3576 \times 10^{-5} \text{ lb/in}^3$ (air at standard atmospheric conditions); $V = 12,204.7 \text{ in/sec}$. (velocity of 310 m/s of mortar round at tab actuation); $C_d = 1.28$ (for rectangular frontal area); $S = 0.322 \text{ in}^2$ (length B of tab \bullet length C of tab); length A of tab = 0.700 in., length B of tab = 0.735 in., and length C of tab = 0.438 in. The drag was equal to 15.5 N or 3.46 lb at 310 m/s in the deployed configuration [3].

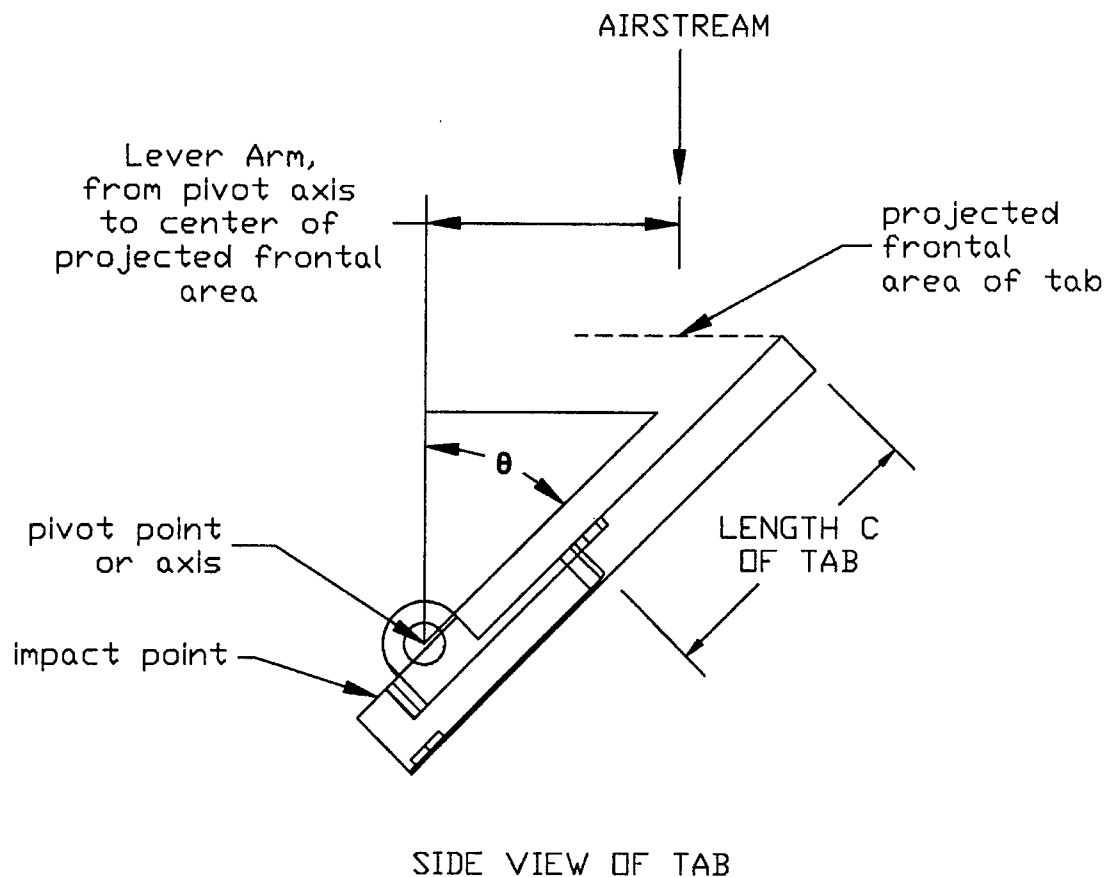


Figure 4. Tab Diagram.

The combined spring damper and air drag loading torque case was run next. The WM3D automatic varying time step option was overridden by the user, and solutions were obtained for time step values of 0.0005 and 0.00005 seconds. The first time step value was chosen to match the hand calculations, while the second was chosen as a means of setting a lower bound for the solution if the actual impact duration between tab and stop were smaller. A "coefficient of restitution" value, which is used in WM3D's impulse-momentum collision model, was input as 0.5. This value is defined as the magnitude ratio of the relative velocities of the colliding bodies immediately before and after the collision. (Note, a coefficient of restitution value of 1.0 means that the collision is perfectly elastic.) Plots of predicted tab angular orientation, angular acceleration, and contact force versus time are shown in Figures 5 through 10. (Note, the contact force reported by WM3D is the collision impulse divided by the time step, "...because the exact duration of the collision, or the shape of the actual collision force profile, is rarely known even in physical experiments.") These predicted data show that for the solution time steps considered (0.0005 and 0.00005 seconds), the tab rotates 90° in approximately 6 msec, with maximum decelerations of 9.61×10^7 to 2.2×10^9 deg./s² and maximum contact forces of 12 to 47 lb, respectively. Understandably, additional runs using higher values of coefficient of restitution and smaller time step values would most likely increase contact force prediction. However, because of time and funding constraints, these scenarios were not explored.

4. CONCLUSION

The combination of dynamic and kinematic analyses has provided confidence in the mortar dragster. Based on the results, the tabs should survive the loading attributable to the deployment into the airstream with a free stream velocity of 310 m/s (1017 ft/s).

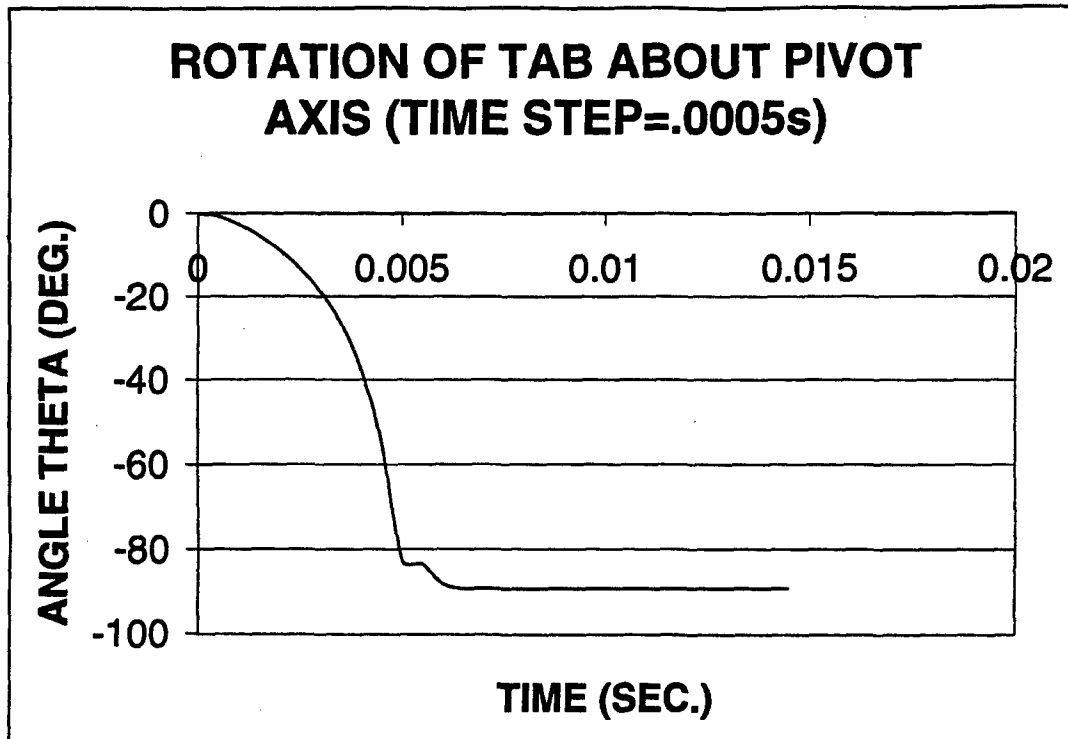


Figure 5. Predicted Rotation of Tab at Time Step of 0.0005 Second.

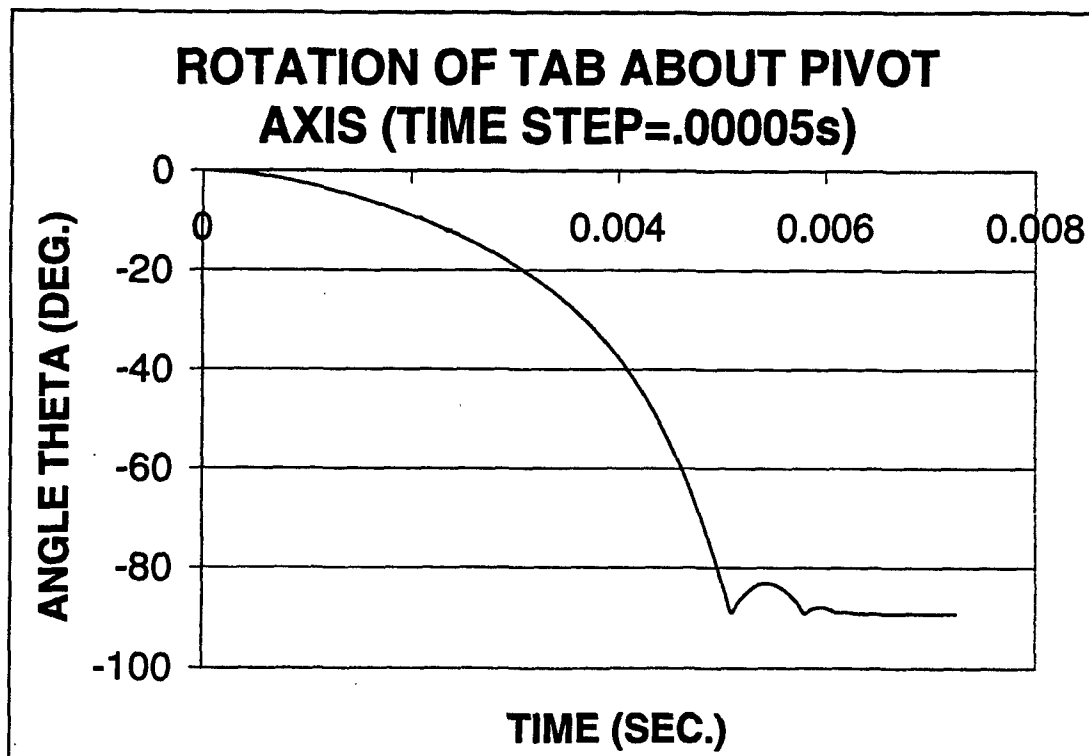


Figure 6. Predicted Rotation of Tab at Time Step of 0.00005 Second.

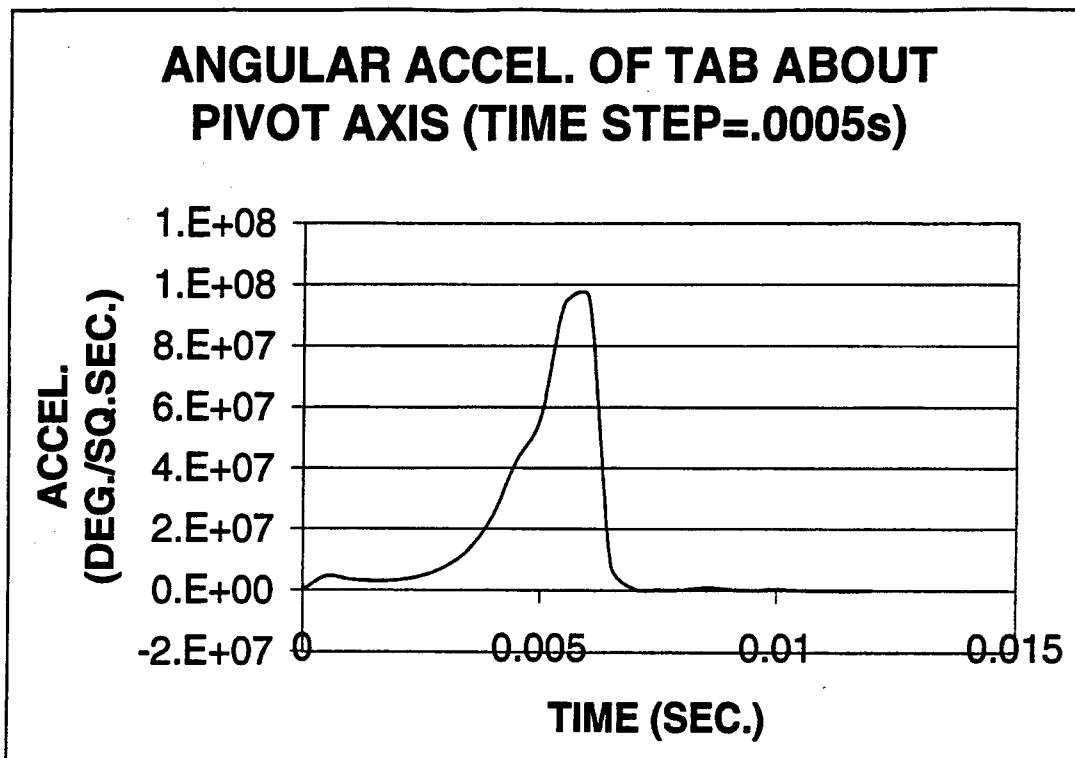


Figure 7. Predicted Angular Acceleration at Time Step of 0.0005 Second.

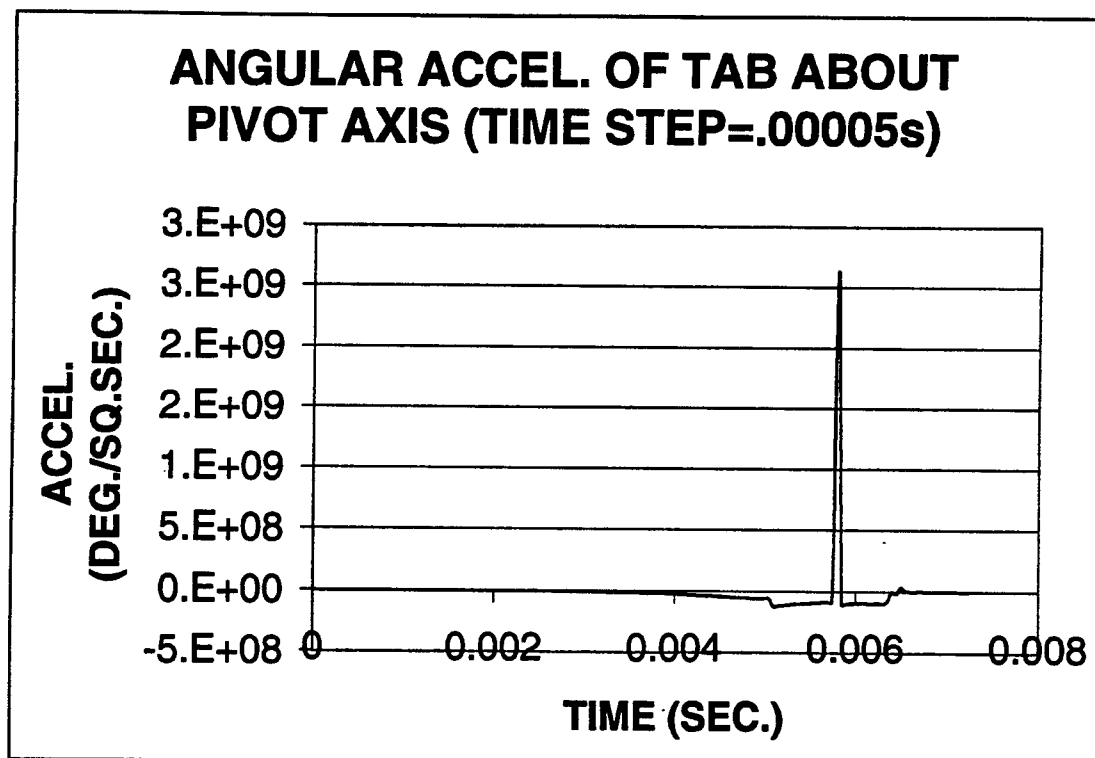


Figure 8. Predicted Angular Acceleration at Time Step of 0.00005 Second.

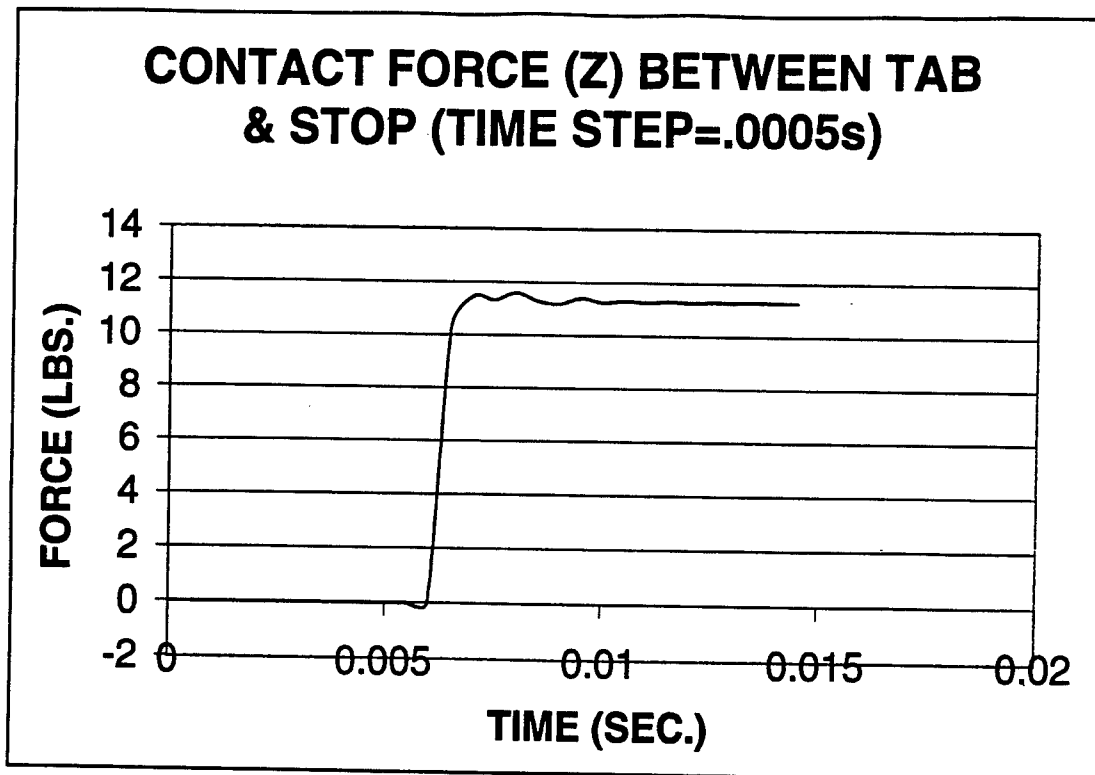


Figure 9. Predicted Contact Force at Time Step of 0.0005 Second.

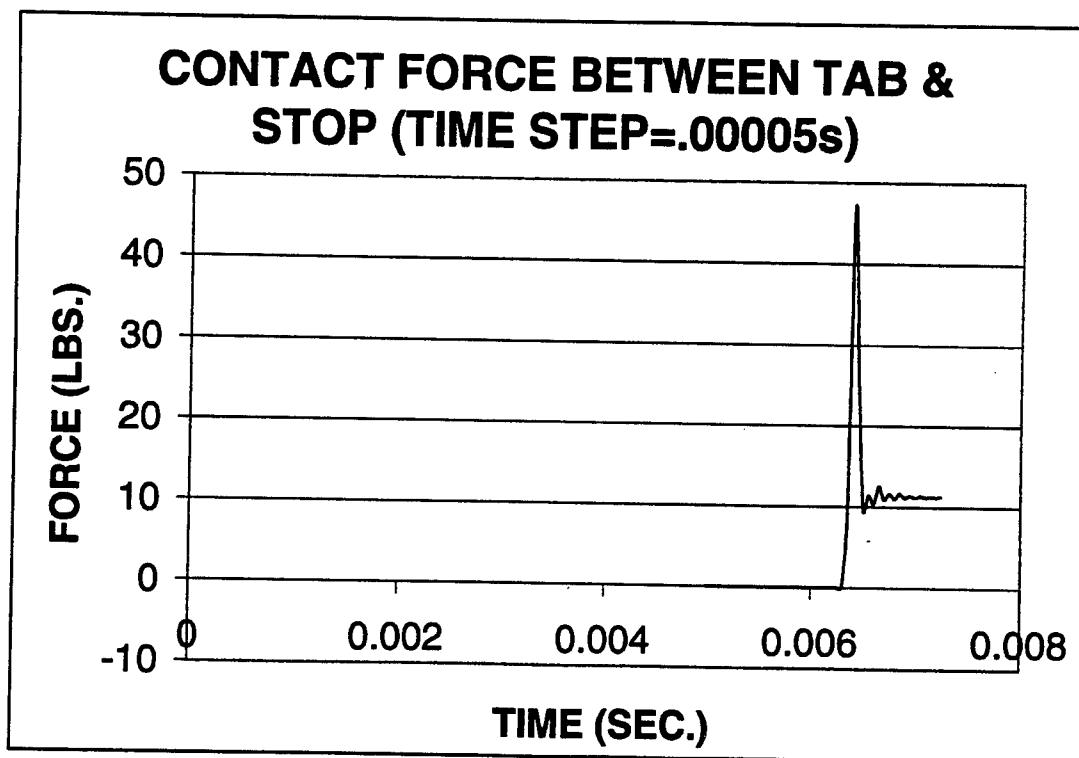


Figure 10. Predicted Contact Force at Time Step of 0.00005 Second.

REFERENCES

1. Working Model® 3D Version 3.0 *User's Manual*, Knowledge Revolution, 66 Bovet Road, Suite 200, San Mateo, California, 94402, 1997.
2. AutoCAD® Release 14 *User's Guide*. Autodesk, Inc., March 1997.
3. Dwinell, J.H. *Principles of Aerodynamics*. McGraw-Hill Book Company, 1949.

INTENTIONALLY LEFT BLANK

NO. OF
COPIES ORGANIZATION

2 ADMINISTRATOR
DEFENSE TECHNICAL INFO CENTER
ATTN DTIC DDA
8725 JOHN J KINGMAN RD STE 0944
FT BELVOIR VA 22060-6218

1 DIRECTOR
US ARMY RESEARCH LABORATORY
ATTN AMSRL CS AL TA REC MGMT
2800 POWDER MILL RD
ADELPHI MD 20783-1197

1 DIRECTOR
US ARMY RESEARCH LABORATORY
ATTN AMSRL CI LL TECH LIB
2800 POWDER MILL RD
ADELPHI MD 20783-1197

1 DIRECTOR
US ARMY RESEARCH LABORATORY
ATTN AMSRL CS AL TP TECH PUB BR
2800 POWDER MILL RD
ADELPHI MD 20783-1197

4 DIRECTOR
US ARMY RSRCH LAB
ATTN AMSRL SS SM J EIKE
J GERBER A LADAS G WILES
2800 POWDER MILL RD
ADELPHI MD 20783-1145

1 HQDA
ATTN SARD T7
F MILTON
WASHINGTON DC 20310-0103

1 HQDA
A77N SARD TT
C NASH
WASHINGTON DC 20310-0103

2 DIRECTOR
US ARMY RSRCH LAB
ATTN AMSRL EP ME
RAY FILLER
DR J VIG
FT MONMOUTH NJ 07703-5601

1 DIRECTOR
US ARMY RSRCH LAB
ATTN AMSRL EP ED
DR R ZETO
FT MONMOUTH NJ 07703-5601

NO. OF
COPIES ORGANIZATION

1 DIRECTOR
US ARMY RSRCH LAB
ATTN AMSRL PS CD
A GOLDBERG
FT MONMOUTH NJ 07703-5601

1 COMMANDER
US ARMY RSRCH OFC
ATTN AMXRO RT IP TECH LIB
PO BOX 122 11
RSCH TRIANGLE PARK NC 27709-2211

13 CMDR US ARMY ARDEC
ATTN AMSTA AR AET A M AMORUSO
E BROWN C CHUNG A FARINA
J GRAU S KAHN K KENDL
C LIVECCHIA C NG G MALEJKO
W TOLEDO B WONG
J THOMASOVICH
PICATINNY ARSENAL NJ 07806-5000

6 CMDR US ARMY ARDEC
ATTN AMSTA FSP A S DEFA0
N GRAY V ILLARDI
S SARULLO R SICIGNANO
PICATINNY ARSENAL NJ 07806-5000

1 COMMANDER
USA DUGWAY PROV GRND
ATTN TECH LIB
DUGWAY UT W22

1 COMMANDER
USA YUMA PROV GRND
ATTN STEYT MT EA C HASTON
YUMA AZ 85365-9110

1 COMMANDER
USA YUMA PROV GRND
ATTN STEYT MAT AT A A HOOPER
YUMA AZ 85365-9110

1 COMMANDER
USA YUMA PROV GRND
ATTN STEYP RS EL R FAULSTICH
YUMA AZ 85365-9110

1 COMMANDER
US ARMY MISSILE COMMAND
ATTN AMSMI RD W WALKER
REDSTONE ARSENAL AL 35898-5000

NO. OF COPIES	ORGANIZATION
2	DIRECTOR US ARMY RTTC ATTN STERT TE F TD R EPPS REDSTONE ARSENAL AL 35898-8052
3	COMMANDER NAVAL SURFACE WARFARE CTR ATTN TECH LIB D HAGEN J FRAYSEE 17320 DAHLGREN RD DAHLGREN VA 22448-5000
1	COMMANDER NAVAL SURFACE WARFARE CTR ATTN TECH LIB SILVER SPRING MD 20903-5000
1	COMMANDER NAVAL SURFACE WARFARE CTR ATTN TECH LIB CHINA LAKE CA 93555-6001
2	COMMANDER NAWC WPN DIV TT&I SYS DPT ATTN D SCOFIELD CODE 3904 S GATTIS CODE C3923 CHINA LAKE CA 93555-6001
1	OFFICER IN CHARGE NAVAL EOD FACILITY ATTN TECH LIB INDIAN HEAD MD 20640
1	ROCKWELL INTL CORP AUTONETICS ELECTR SYS DIV ATTN R CHRISTIANSEN 3370 MIRALOMA AVE PO BOX 3105 ANAHEIM CA 92803-3105
2	CHLS STARK DRAPER LAB INC ATTN J ELWELL J SITOMER 555 TECHNOLOGY SQUARE CAMBRIDGE MA 02139-3563
1	INTERSTATE ELECTR CORP ATTN J GRACE 1001 E BALL RD ANAHEIM CA 92803
1	INTERSTATE ELECTR CORP ATTN I REIDER 1735 JEFFERSON DAVIS HWY STE 905 ARLINGTON VA 22202

NO. OF COPIES	ORGANIZATION
2	DYNAMIC SCIENCE INC ATTN S ZARDAS P NEUMAN PO BOX N ABERDEEN MD 21001
2	ARROW TECH ASSOCIATES INC ATTN R WHYTE W HATHAWAY 1233 SHELBOURNE RD STE D8 SOUTH BURLINGTON VT 05403
1	PICO SYSTEMS INC ELECTRONIC PKG & TECH DEPT ATTN J BANKER PO BOX 134001 ANN ARBOR MI 48113-4001
1	ROCKWELL INTNL CORP COMM DIV ATTN D DEALE 350 COLLINS RD NE CEDAR RAPIDS IA 52498
5	WORKING MODEL INC SUITE 200 ATTN M HAYWOOD 66 BOVET ROAD SAN MATEO CA 94402
	<u>ABERDEEN PROVING GROUND</u>
2	DIRECTOR US ARMY RESEARCH LABORATORY ATTN AMSRL CI LP (TECH LIB) BLDG 305 APG AA
2	DIR USARL ATTN AMSRL WM I MAY J ROCCHIO
2	DIR USARL ATTN AMSRL WM B A HORST H ROGERS
15	DIR USARL ATTN AMSRL WM BA F BRANDON T BROWN L BURKE J CONDON (5 CYS) W DAMICO B DAVIS T HARKINS D HEPNER M HOLLIS V LEITZKE A THOMPSON
4	DIR USARL ATTN AMSRL WM BC B GUIDOS P PLOSTINS D LYONS S WILKERSON

NO. OF COPIES	ORGANIZATION
1	DIR USARL ATTN AMSRL WM BD B FORCH
1	DIR USARL ATTN AMSRL WM BE G KELLER
1	DIR USARL ATTN AMSRL WB BF J LACETERA
3	DIR USARL ATTN AMSRL WM BB C SHOEMAKER T VONG R VONWALDE
2	DIR USARL ATTN AMSRL WM MB B BURNS L BURTON
1	DIR USARL ATTN AMSRL IS EE R LOUCKS
2	DIR USARL ATTN AMSRL WT TD N GNIAZDOWSKI F GREGORY
1	DIR USARL ATTN AMSRL WT TB R LOTTERO
1	DIR USARL ATTN AMSRL WM PD T ERLINE

INTENTIONALLY LEFT BLANK

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY (Leave blank)		2. REPORT DATE April 1998		3. REPORT TYPE AND DATES COVERED Final	
4. TITLE AND SUBTITLE Dynamic Analyses of the Mortar Dragster Tab Mechanism				5. FUNDING NUMBERS PR: 1L162618AH80	
6. AUTHOR(S) Condon, J.A.; Hollis, M.S.L. (both of ARL)					
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Weapons & Materials Research Directorate Aberdeen Proving Ground, MD 21010-5066				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) U.S. Army Research Laboratory Weapons & Materials Research Directorate Aberdeen Proving Ground, MD 21010-5066				10. SPONSORING/MONITORING AGENCY REPORT NUMBER ARL-TN-107	
11. SUPPLEMENTARY NOTES					
12a. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release; distribution is unlimited.				12b. DISTRIBUTION CODE	
13. ABSTRACT (Maximum 200 words) As a means of verifying the design and operation of the Mortar Dragster, a commercially available, three-dimensional rigid body dynamics simulation program was exercised. The Mortar Dragster is a conceptual design for a range correction device for the 81-mm mortar. The design includes a series of drag surfaces, or tabs, which are actuated at some point in the trajectory of the projectile. The actuation places the entire series of drag surfaces into the airstream, thus slowing the projectile. Of specific interest are the collision forces and resulting tab hinge loads imparted by the opening tabs impacting the adjacent connected body because of integral torsion springs and air drag-induced torque loads. Collision forces predicted by the simulation program were of the same order of magnitude as hand calculations. The results of this investigation provided confidence in the final design of the tab mechanism before its flight testing and also provided further verification of the simulation program's performance.					
14. SUBJECT TERMS contact force impact drag module				15. NUMBER OF PAGES 25	
				16. PRICE CODE	
17. SECURITY CLASSIFICATION OF REPORT Unclassified	18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified	19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified	20. LIMITATION OF ABSTRACT		